Microturbines: Activities within the Office of Distributed Energy Resources

Debbie Haught

Office of Power Technologies, U.S. Department of Energy

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DER Microturbine Activities

- Baseline Microturbine Testing
  - University of California-Irvine (UCI) & Southern California Edison (SCE)
  - National Rural Electric Cooperative Association (NRECA)
- Advanced Microturbine Technology Program
  - Program planning with Industry
    - Workshop – 11/98
    - Program Plan – 12/99
  - Competitive solicitation, 6 awards announced 7/00
- Supporting Materials Technology Projects

Baseline Microturbine Evaluation Program

- $2.9+ Million Program begun by Southern CA Edison and University of CA-Irvine in 1996
- Funded by: SCE, DOE, CEC, EPRI, CERA, CERTS
- Project Goal:
  - Determine the availability, operability, reliability and performance characteristics of commercially available microturbines
- Project Objectives
  - Compare manufacturer claims to actual experiences from installation, operation and testing of units
  - Assess microturbine performance against SCAQMD emissions rule and IEEE power quality standards

Test Bed at U.C. Irvine

- 4 test bays
- 400 amp 480 volt service
- 100 psig natural gas with ability to blend for lower Btu gas testing
- Cogen heat dissipation ability
- Instrumentation for gas and electricity and electronic data acquisition
- Standardized testing procedures
- Veteran on-site two-person testing crew
- Ability to do specialized/custom testing

Highly visible test site – conducted tours for numerous visitors

Testing Experience

MTG	Installation Date	Total Op Hours	Status
Capstone "B" 30 kW	Jan-97	958	Completed
Capstone "B" 30 kW	Jan-97	967	Completed
Capstone 10 Pack	Apr-97	26	Completed
Capstone "C" 30 kW	May-97	3794	Completed
Capstone "C" 30 kW	Jul-97	2079	Completed
Bowman 35 kW	Feb-99	100	Completed
Bowman 60 kW	Jun-99	60	Completed
Capstone HP 30 kW	Apr-99	16656	Operating
Parallon 75 kW	Jun-00	5806	Completed
Capstone LP 30 kW	Aug-00	9452	Operating
Bowman 80 kW	Jun-01	2407	Operating

Capstone HP 28 kW

- Model 330 rated output: 28 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Equipped with a low NOx combustor
- Not equipped with a waste heat recovery boiler
- Fourth generation unit

Capstone 28 kW Results

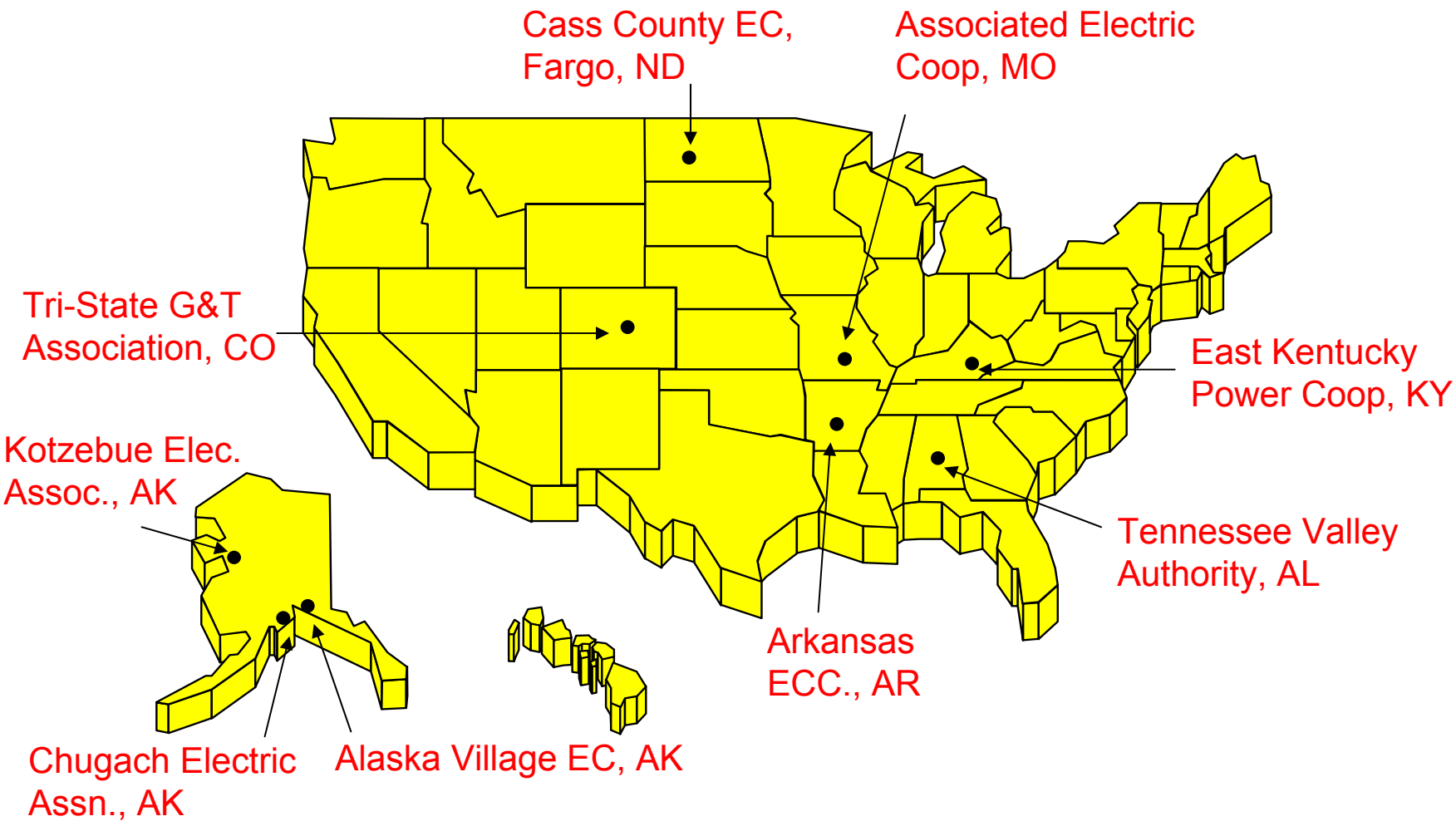
- Several overspeed trips were resulting from flame control algorithm; Capstone remotely downloaded revised control system software; no overspeed trips since software revised
- Reliable operation following resolution of overspeed
- Comparing manufacturer's efficiency and heat rate claims with test results converted to a common basis, resulted in testing results consistent with claims as shown below @ 70°F, about sea level, and LHV:

	(tested)	(claimed)
Efficiency	23.7% ± 0.45%	24.5% ± 0.5%
Heat rate	14,415 BTU/kWh	13,931 BTU/kWh

Microturbine Field Tests at U.S. Rural Electric Cooperatives

- Project Partners: National Rural Electric Cooperative Assn. (NRECA) Central Research Network (CRN), ORNL, EPRI
- Conduct nationwide field tests of microturbines from several different manufacturers
- Collect application and operation data on microturbine installation and performance
- Assess microturbine feasibility and reliability in diverse applications and environments
- Benchmark future improvements in microturbine performance, operation, and maintenance

Participating Co-ops and Sites



Specifics of Each Co-op Field Test

#	Coop	MTG*	Thermal Recovery	Application	Location	Install Date
1	AVEC	C 30-kW	Space Heating	Warehouse and Office	Anchorage, AK	Apr-01
2	Arkansas Electric	H 75-kW	Boiler Freeze Protection	Power at Generating Facility	Agusta, AR	May-01
3	Associated Electric	E 45-kW	TBD	Power for city water pumps	Kearney, MO	Jul-01
4	Cass County	C 30-kW	Preheat and Feed Hot Water Boilers	Hotel and Convention Center	Fargo, ND	Aug-00
5	Chugach	C 30-kW	TBD	Warehouse and Office	Anchorage, AK	Oct-00
6	East Kentucky	E 80-kW	TBD	Power at Generating Facility	Winchester, KY	2002
7	Kotzebue Electric	C 60-kW	TBD	Power plant and later a commercial customer	Kotzebue, AK	Jan-02
8	Tennessee Valley Authority	C 30-kW	None	TVA Power Institute R&D Building	Muscle Shoals, AL	May-00
9	Tri-State G&T	I 70-kW	Preheat Irrigation Water	Industrial Greenhouse	Brigton, CO	Dec-01

*C-Capstone, H-Honeywell (being replaced by 80-kW Elliott), E-Elliott, I-Ingersoll-Rand

Sites That Have Operating Microturbines

Cooperative	Microturbine	Fuel, Connection	Operating Hours
AVEC	Capstone 30-kW	Oil-fired, grid-parallel	
Arkansas Electric	Honeywell 75-kW*	Gas-fired, grid-parallel	
Associated Electric	Elliott 45-kW	Gas-fired, grid-parallel	
Cass County Electric	Capstone 30-kW	Gas-fired, grid-independent	~8,000 hours
Chugach	Capstone 30-kW	Gas-fired, grid-parallel	~8,000 hours
Tennessee Valley Authority	Capstone 30-kW	Gas-fired, grid-parallel	~700 hours

*Being returned to Honeywell and to be replaced by 80-kW Elliott

Advanced Microturbine Program

- Six year program (FY 2000 - 2006), $60+ million Govt. investment
- Program to include:
  - Competitive solicitation(s) for engine conceptual design, development, and demonstration; component, sub-sub-system development
  - Competitive solicitation(s) for technology base in areas such as materials, combustion, sensors and controls, etc
  - Technology evaluations and demonstrations
- End-use applications open to include stationary power applications in industrial, commercial, and institutional sectors

Advanced Microturbine Program Goals

Next Generation Microturbine System (< 1,000 kW) by 2006 :

- **High Efficiency** - Fuel-to-electricity conversion efficiency of at least 40%
- **Environmental Superiority** - NOx < 7 ppm (natural gas)
- **Durable** - 11,000 hours of reliable operations between major overhauls and a service life of at least 45,000 hours
- **Economical** - System costs < $500/kw, costs of electricity that are competitive with the alternatives (including grid) for market applications
- **Fuel Flexible** - Options for using multiple fuels including diesel, ethanol, landfill gas, bio-fuels

Advanced Microturbine Projects

2000

- 17-30% Efficiency (LHV*)
- Double digit ppm NO_x

FY00 – 6 Awards

- Ingersoll-Rand
- UTC
- GE
- Honeywell
- Capstone
- Solar

Average cost share for total program ~ 50%, staged over development – 30, 45, 60%

2007

- 40% Efficiency (LHV*)
- Single digit ppm NO_x

** Lower Heating Value*

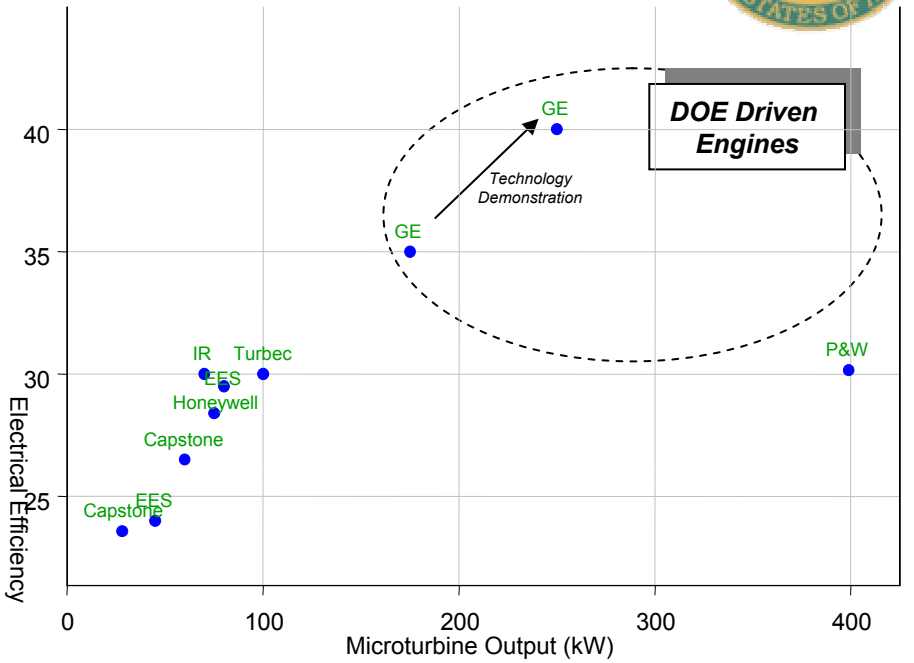
GE Advanced Microturbine Program Overview

Demonstration of Component Performance, Advanced Technologies and Materials for a 175 – 350 kW 40 % microturbine with single digit emissions at $500 /kW.

3 year Cost Shared Program ($4.7M DOE)

Technologies

- Advanced recuperator design
- Low emission combustion system
- Advanced sealing and material usage
- State-of-the art power electronics and controls
- Compressor and turbine advanced turbomachinery design methodology



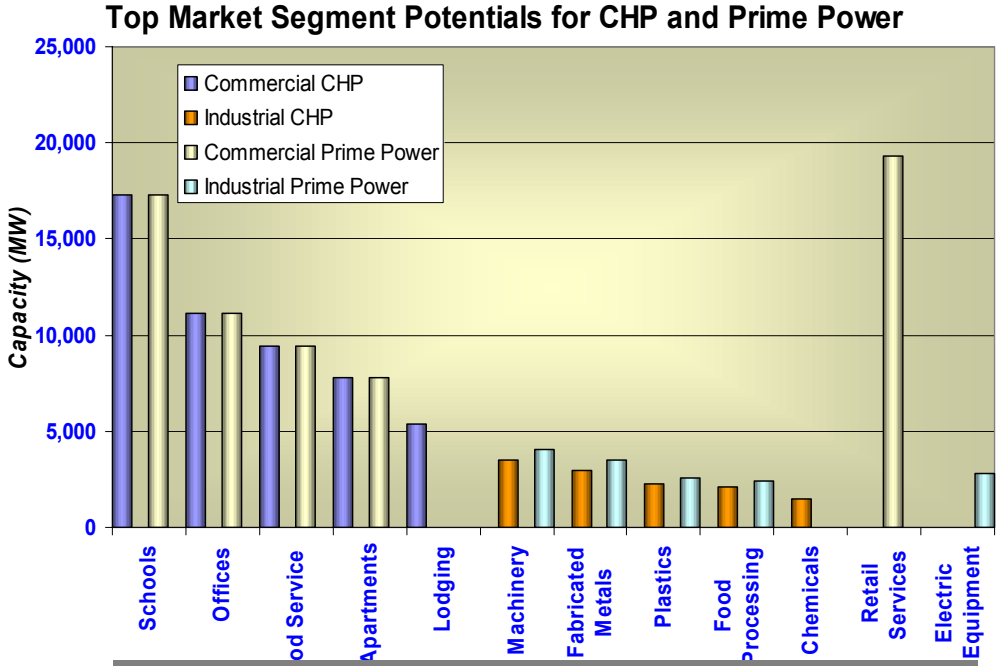
SCHEDULE Milestones/Deliverables	Scheduled Completion Date	Status (complete, in progress, planned, ...)
• Subtask A – Market Study	12-31-00	Complete
• Task 1 – Conceptual Design	4-1-01	Complete
• Task 2 – Component Design	7-1-03	In Progress
• Task 3 – System Design	7-1-03	In Progress
• Task 4 – Laboratory Evaluation	12-31-03	Planned
• Task 5 – Demonstration	9-29-04	Planned

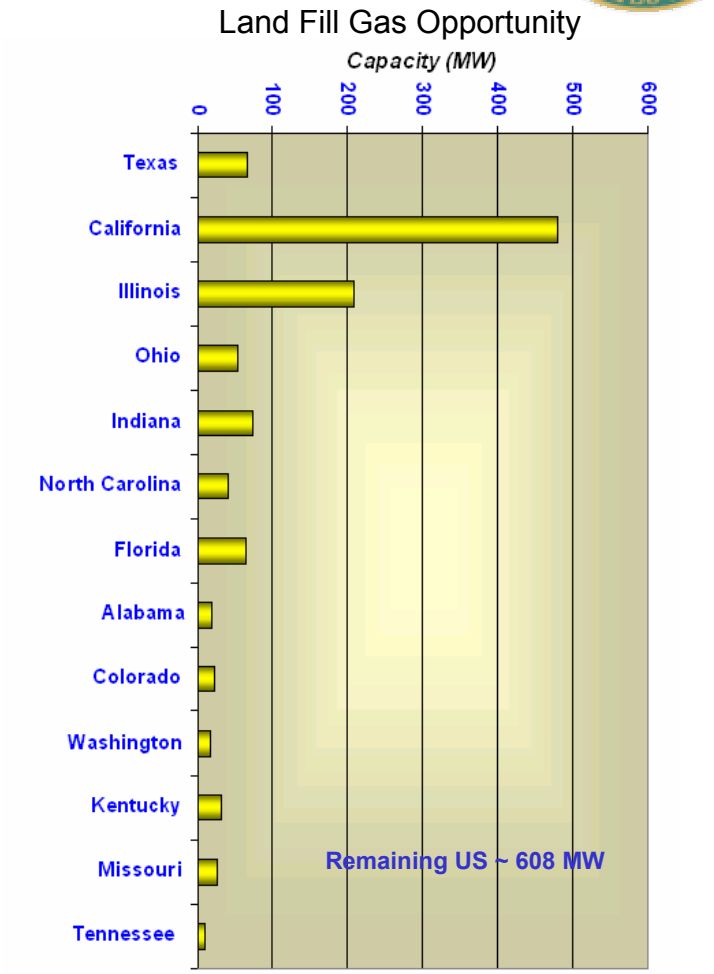
Program Team

- GE Corporate Research and Development
- GE Power Systems
- GE Industrial Systems
- Kyocera
- Turbo Genset
- *Others Pending …*

Aggressive Program that is Pushing the State of the Art

Cumulative Market Potentials Through 2010





Total DG Market Potential Through 2010		
	CHP	Prime Power
Commercial	*50,900 MW*	*64,923 MW*
Industrial	*12,250 MW*	*15,325 MW*

Potentially Significant Opportunity for Distributed Generation

Source: Onsite Energy Corporation Market Study – Spring 2001 (Includes all DG Potential)

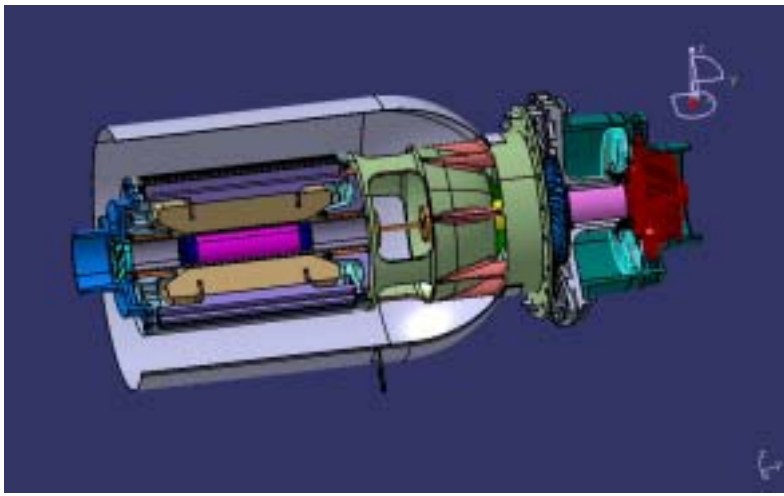
Capstone Turbine – Advanced Microturbine Program

DOE Funding: $10.0 M over 5 years

Partners: Honeywell Ceramic Components, COI Ceramics, Goodrich, Haynes, J.H. Benedict, ORNL, UC Irvine

Completed design concept for 200 – 300 kW microturbine with

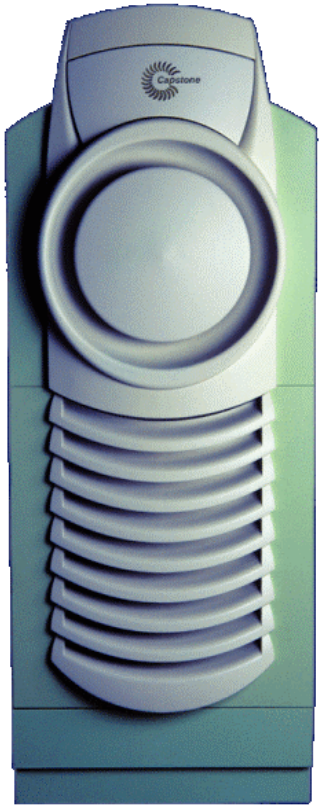
- Single shaft
- Air bearings
- Annular recuperator
- Low emission annular combustor
- Centrifugal compressor and radial turbine



Engine core of advanced microturbine

Capstone Microturbine Program Strategy

- Initial “Metal Development” (MD) unit incorporating experience from design of 30 & 60 kW units
  - Spin off as initial product to market
- Design in enhancements such as increased operating temperature and advanced materials for “High Efficiency” (HE) unit to meet program goals

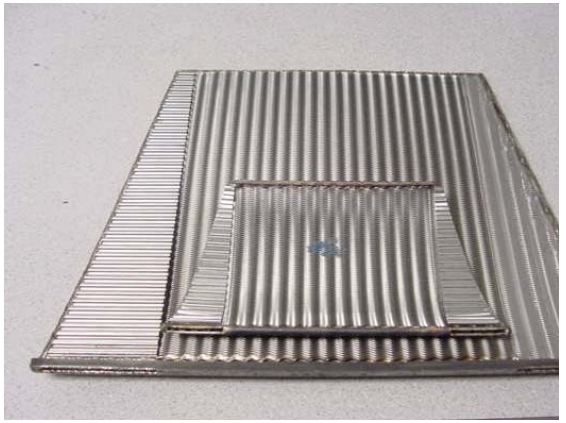


Capstone Program Accomplishments

- Completed preliminary design review and initiated detail design of “metallic development” engine
- Initiated recuperator detailed analysis and recuperator process development
- Beginning screening and evaluation of high temperature materials for recuperators and hot section components
- Completed marketing study

Capstone – Recuperator Development Activities

- High effectiveness required for high efficiency
- Advanced CFD analysis to optimize flow
- Rig to validate analysis
- Concurrent engineering for increased producability



C60 and AMTS cells

Recuperator Test Rig

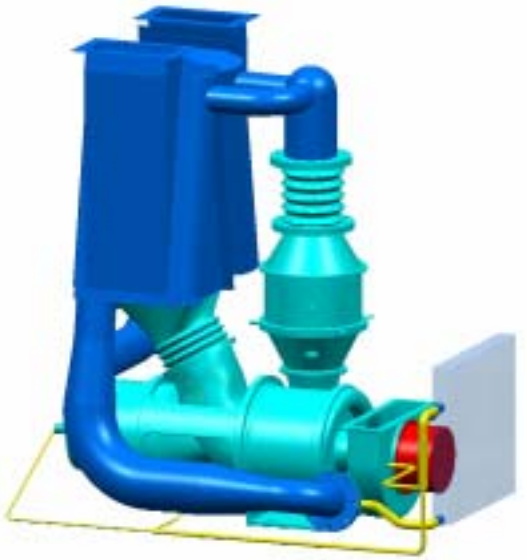
Capstone Program Major Milestones

- **Metallic Development Unit**
  - Complete preliminary design – 7/01
  - Critical design review – 9/02
  - Simple cycle 100% power operation – 12/02
  - Full power operation – 3/03

- **High Efficiency Unit**
  - Complete preliminary design – 7/01
  - Critical design review – 6/03
  - Complete first recuperator core – 6/03
  - Full power operation – 5/04
  - Initiate field test – 10/04

UTRC - Advanced Microturbine Program

- DOE Funding: $8.6 M over 5 years
- Partners: **DTE Energy, P&W Canada, TurboGenset, Hamilton Sundstrand, SatCon, ORNL**



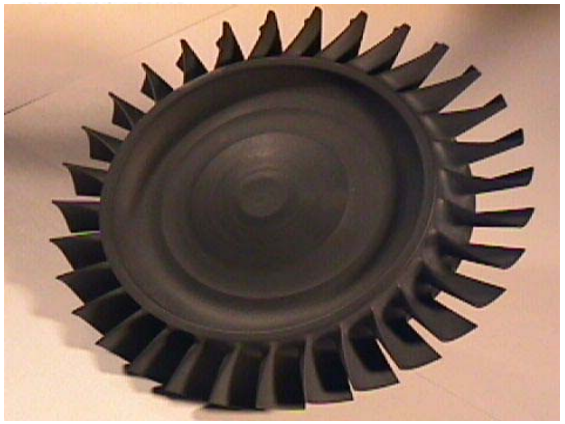
- Approach: Demonstrate new product capability of enhanced ENT-400 microturbine system (ST5 Plus)
  - **400-kW class recuperated microturbine based on PWC ST5 engine, 30% electrical efficiency**
  - **Launched in July 2000 through partnership of DTE Energy Technologies, P&W Canada, and TurboGenset**
  - **Initial product delivery in March 2002**

UTRC Advanced Microturbine System Approach

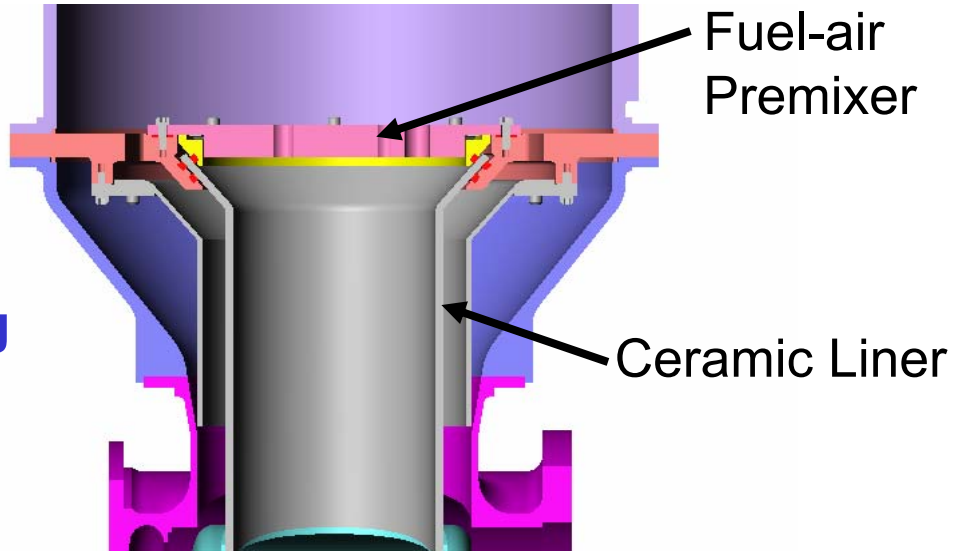
- 3-Part Strategy for >40% Electrical Efficiency
  - Increase turbine inlet temperature using uncooled, ceramic hot section components
  - Increase power generation/conversion efficiency
  - Convert exhaust energy with Organic Rankine Cycle (ORC)
- Key Technologies
  - Ceramics
  - Advanced recuperator materials
  - ORC cycle
  - Low emissions combustion
  - Electrical generation/conversion systems

UTRC Accomplishments

- **Completed preliminary design of ceramic integrally bladed rotor (IBR)**
  - Reduced blade count
  - An order of magnitude more foreign object damage (FOD) tolerant than ceramic blades based on metal design



- **Completed preliminary design of low emissions combustor**
  - Ceramic liner reduces cooling airflow and enhances turndown
  - Stress/life analyses permit use of lower cost ceramics



UTRC Microturbine Organic Rankine Cycle

Completed preliminary design of ORC and assembled ORC prototype.

In preliminary tests, ORC system produced 60 kW from Waste Heat.

Condensers

Vapor Generator

Pumps

Turbine/Generator

UTRC Major Program Milestones

- Complete preliminary design of key subsystems
  - Low NOx combustor: 8/01
  - ORC system: 4/01
  - Ceramic turbine: 12/01
- Demonstrate subsystem/component performance
  - 80 kW from ORC subsystem : 1/02
  - Low NOx combustor - < 7 ppm NOx, CO < 10 ppm over 70 – 100% power: 11/02
  - Design and fabricate ceramic vanes and integrally bladed rotor: 12/02
- System modification/ subsysem integration: 9/03
  - 5 point increase in efficiency with microturbine/ORC system: 7/02
  - Full advanced technology integration: 9/03
- Factory performance test: 3/04
- Initiate field test: 1/05

Advanced Materials for Microturbines

- Advanced materials are a key enabling technology for advanced microturbines:
  - Monolithic ceramics: hot section components, combustor liners
  - Ceramic composites: combustor liners
  - High temperature metal foils: recuperators
  - High conductivity carbon foam: power electronics
- A materials program to support microturbines is underway and managed by ORNL
  - Program designed to meet needs of advanced microturbine developers to develop materials technology base
  - “Peer Review” held June 2001

Examples of Program Coordination

- External Coordination
  - States (CEC, NYSERDA)
    - CEC EPAG solicitation
    - NYSERDA solicitations
  - EPRI
  - Natural Resources Canada (CANMET)
- Internal DOE
  - Industrial Gas Turbines (materials and low emissions)
  - Integrated Energy Systems (DER)
  - CHP (DER)
  - Interconnection (DER)
  - Industrial Distributed Generation (DER)
  - Energy Storage (DER)
  - Micro-Grid/Integration (DER/CERTS)
  - Fuel cell hybrid systems (FE)
  - Federal sites (FEMP)

Summary

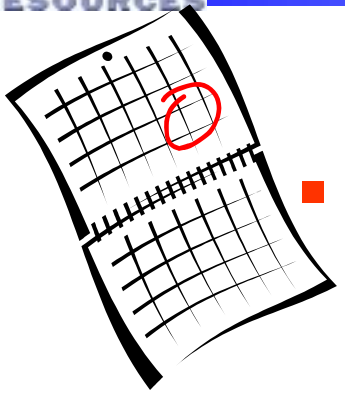
- Microturbines are an emerging technology choice in DER markets and applications
- Public/private partnerships have been established to develop “next-generation” microturbines
- Key technology challenges need to be overcome to meet program goals

For Additional Information

www.eren.doe.gov/der

- Debbie Haught, 202.586.2211, debbie.haught@ee.doe.gov
- Steve Waslo 630.252.2143, stephen.waslo@ch.doe.gov
- Dave Stinton 423.574.4556, stintondp@ornl.gov

Mark Your Calendars



- Workshop on Microturbine Applications Jan 17-18, 2002 College Park, MD

- DOE DER Gas Turbine and Microturbine Peer Review, March 12-14, 2002 Fairfax, VA